

RESEARCH MEMORANDUM

DRAG INVESTIGATION OF SOME FIN CONFIGURATIONS

FOR BOOSTER ROCKETS AT MACH NUMBERS

BETWEEN 0.5 AND 1.4

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SUMMARY

Flight tests have been made with rocket-propelled models to furnish data for booster drag estimates and to investigate the drag of various booster fin configurations. Model booster fins of a type extensively used by the NACA were flown through a Mach number range of 0.5 to 1.4. Several tie-rod-braced fin assemblies were investigated with various arrangements of the tie rods, and a single cantilever fin assembly was tested. A breakdown of the drag due to the structural components of the tie-rod-braced fins was also determined from tests on several additional booster fin arrangements. The data from this investigation may be used in estimating the drag of booster fin assemblies which are somewhat similar to those of the present tests.

The drag of tie-rod-braced fin assemblies was found to be largely dependent upon the types of and arrangement of the tie rods. A structurally practical cantilever fin assembly had approximately the same drag coefficients as the most efficient tie-rod-braced fin assembly of this investigation.

INTRODUCTION

The drag of the booster is one of the factors which limits the maximum attainable Mach numbers of rocket-boosted vehicles. Few data are available at transonic and supersonic speeds for estimating the drag of the booster components. Some data on the drag of a typical booster assembly were obtained by the NACA during the course of tests on rocket-booster research models and indicated that the drag of the booster fin assembly was excessive. It was thought that this was caused mainly by the drag of the tie-rod bracing. A drag investigation of this booster fin assembly was therefore conducted and a design incorporating cantilever fins was built and tested.

Flight tests were made of several zero-lift drag models having booster fin assemblies with tie-rod-braced fins and of a single model having a booster fin assembly with cantilever fins. These fin assemblies are similar to those used on booster rockets fired at the Pilotless Aircraft Research Station, Wallops Island, Va. In addition, several modifications to the tie-rod-braced fin assemblies were investigated in order to determine a breakdown of the drag resulting from the structural components. Data are presented as drag in coefficient form for the various configurations and a drag curve in pounds per foot of projected rod length (that is, projected on a plane normal to the center line of the body) for the particular size tie rods tested is shown.

MODELS AND FLIGHT TESTS

The models used in this investigation are shown in figures 1 and 2. The model booster fins (table I) were mounted on a cylindrical body which has been extensively used in zero-lift drag investigations (reference 1). The tie-rod-braced booster fins had an aspect ratio of 2.04, sweep angle of the leading edge of 45° , taper ratio of 0.37, and a thickness ratio of 4.02 percent at the mean aerodynamic chord. The cantilever model booster fins had an aspect ratio of 3.20, sweep angle of the leading edge of 34° , taper ratio of 0.32, and a constant 5-percent thickness ratio. The blunt trailing edges on the present booster fins were dictated by the ease of fabrication and the lessened susceptibility to damage in handling.

The fins and root attachments of the tie-rod-braced configurations were especially constructed for this investigation with sufficient strength for flight test without the tie rods in order that breakdown tests to determine the drag of the components could be made. Only the completely braced tie-rod configurations are considered structurally practical for an actual booster application with these fins. The practical tie-rod-braced configurations flown were: the parallel round tie rod assembly, the crossed round-tie-rod assembly, and the crossed flat-tie-rod assembly. On the configuration having crossed flat tie rods, the rods were rigidly fastened together where they crossed. The cross-sectional area of the round and flat tie rods was approximately equal for similar configurations. The fins were restrained at their roots by an external fitting constructed of 0.091 channels and 0.032 web stiffeners.

Three additional models were tested which were identical to the parallel round-tie-rod assembly (above) with the exception of the following modifications: (1) with the rear tie rods removed, (2) with the forward and rear tie rods removed, and (3) with forward and rear tie rods removed and with the external root fitting removed.

The cantilever fin assembly was representative of a structurally practical arrangement in use on boosters by the NACA. It was designed to carry approximately twice the load of the tie-rod-braced fin assembly and

therefore the two configurations are not structurally equivalent. This should be kept in mind when comparisons of the drag are made.

The models flown in this investigation were launched from a guide-rail launcher at an angle of 70° from horizontal. All models were boosted with 5-inch HVAR rocket motors and had 3.25-inch aircraft rocket-motor sustainers.

Reynolds number variation with Mach number is presented in figure 3. The Reynolds numbers are based on mean aerodynamic chord (R_C) and on round-tie-rod diameter (R_d).

Instrumentation and Data

The instrumentation in this investigation consisted of Doppler radar for velocity, tracking radar for flight paths, radiosondes for atmospheric conditions, and tracking cameras. A brief discussion of the instrumentation and of the data reduction may be found in reference 1.

Drag coefficients were obtained during coasting flight by the following relation:

$$C_D = \frac{-2W(a + g \sin \theta)}{g\rho S V^2}$$

where

W model weight with propellant expended

a acceleration obtained by differentiation of the Doppler velocity-time curve

θ flight-path angle obtained from tracking radar

S exposed area of the four fins

The exposed areas for the fins tested were 3.37 square feet for the tie-rod-braced fin assembly and 7.52 square feet for the cantilever fin assembly.

The accuracy of the data in this investigation is believed to be within ± 3 percent of the measured values over the test range covered.

DISCUSSION

Rod-Braced Fin Assemblies

The total drag coefficients based on exposed fin area for the test models with tie-rod-braced fin assemblies are presented in figure 4, which also includes the drag coefficients for the body alone obtained from an estimated body drag which is believed to be sufficiently accurate for this investigation.

Using the drag-coefficient curves shown in figure 4, the drag coefficients for the various fin assemblies were obtained by subtracting body drag from complete model drag and are presented in figure 5. The drag coefficients obtained in this manner include unknown interference effects.

A comparison of the three practical fin assemblies shows that crossing the round rods had little effect on drag, but that substituting flat for round rods reduced the fin assembly drag considerably. The drag of the fin assemblies which are modifications of the parallel round-tie-rod assembly are also shown in figure 5. The results show that removing the rear tie rods reduced the assembly drag by approximately 15 percent, removing the rods altogether reduced the drag by approximately 40 percent, and removing the rods and the root fittings reduced the drag approximately 50 percent.

In figure 6, incremental drag coefficients for the various fin-assembly components plus interference are presented. The drag coefficients of the tie rods were obtained from the curves of figure 5 by subtracting the drag of the assembly without tie rods from the drags of the various fin assemblies.

The root-fitting-plus-interference drag coefficients were obtained as the difference in drag between the fins with and without external root fittings. The drag of the root fitting for this configuration was small and a modification of this component would not reduce the total drag by an appreciable amount.

The single-round-rod configuration, with the tie rod in the forward position, was flown to determine the effect of the front tie rod on a second rod in parallel. In a comparison of the single-round-rod configuration with the parallel-round-rod configuration in figure 6, the second rod is shown to have approximately one half the drag of the front rod.

The assembly with crossed round rods was flown to investigate this type of practical booster assembly. Although crossing the round tie rods may have increased the effective frontal area, the observed result was approximately that to be expected from pure sweep considerations.

Tie-rod drag in pounds per foot of projected rod length (projected on a plane normal to the center line of the body) including end fittings and interference are presented in figure 7. The saving in drag of flat rods over round rods of the same tensile strength is evident for the particular rod sizes tested.

In a comparison of the round tie rods flown in the forward position in this investigation and the circular cylinders tested in reference 2, for approximately the same rod sizes, the drag coefficients were: in

this investigation, $M = 0.5$, $R_d = 2.6 \times 10^4$, $C_D = 1.5$; in reference 2, $M = 0.5$, $R_d = 2.6 \times 10^4$, $C_D = 1.35$. The drag coefficients in this comparison are based on the frontal area of the rods. The difference in these drag coefficients may be caused by the interference effects and the end fittings which were present on the tie rods used in this investigation.

Cantilever Fin Assembly

The results of the test of the structurally practical booster assembly design incorporating cantilever fins are given in figure 8 and show that the cantilever configuration has approximately the same drag coefficients as the flat-crossed-rod configuration of the rod-braced assemblies.

The cantilever assembly fin was designed for a greater load and had a higher aspect ratio than the rod-braced assembly fin and a slightly higher weight per square foot of fin area. The failure to realize the full drag reduction possible by eliminating the tie rods was caused by the increased thickness ratio of the fins required for strength, the reduced sweep of the leading edge on the cantilever fin assembly, and the roughness of the corrugated root fitting.

CONCLUSIONS

Using the data from this investigation, drag estimates may be made for boosters similar to those of the present tests. Within the scope of this investigation the following conclusions were reached:

1. The drag of practical tie-rod-braced fin assemblies was found to be largely dependent upon the types of and arrangement of the tie rods.
2. A structurally practical cantilever fin assembly had approximately the same drag coefficients as the most efficient tie-rod-braced fin assembly tested.
3. Crossing the tie rods did not reduce the drag by an appreciable amount.
4. The rear rod in the parallel-tie-rod fin assembly had approximately one-half the drag of the rod in the forward position.

5. The contribution of the root fitting to the drag of the rod-braced fin assembly was small.

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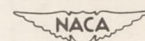
REFERENCES

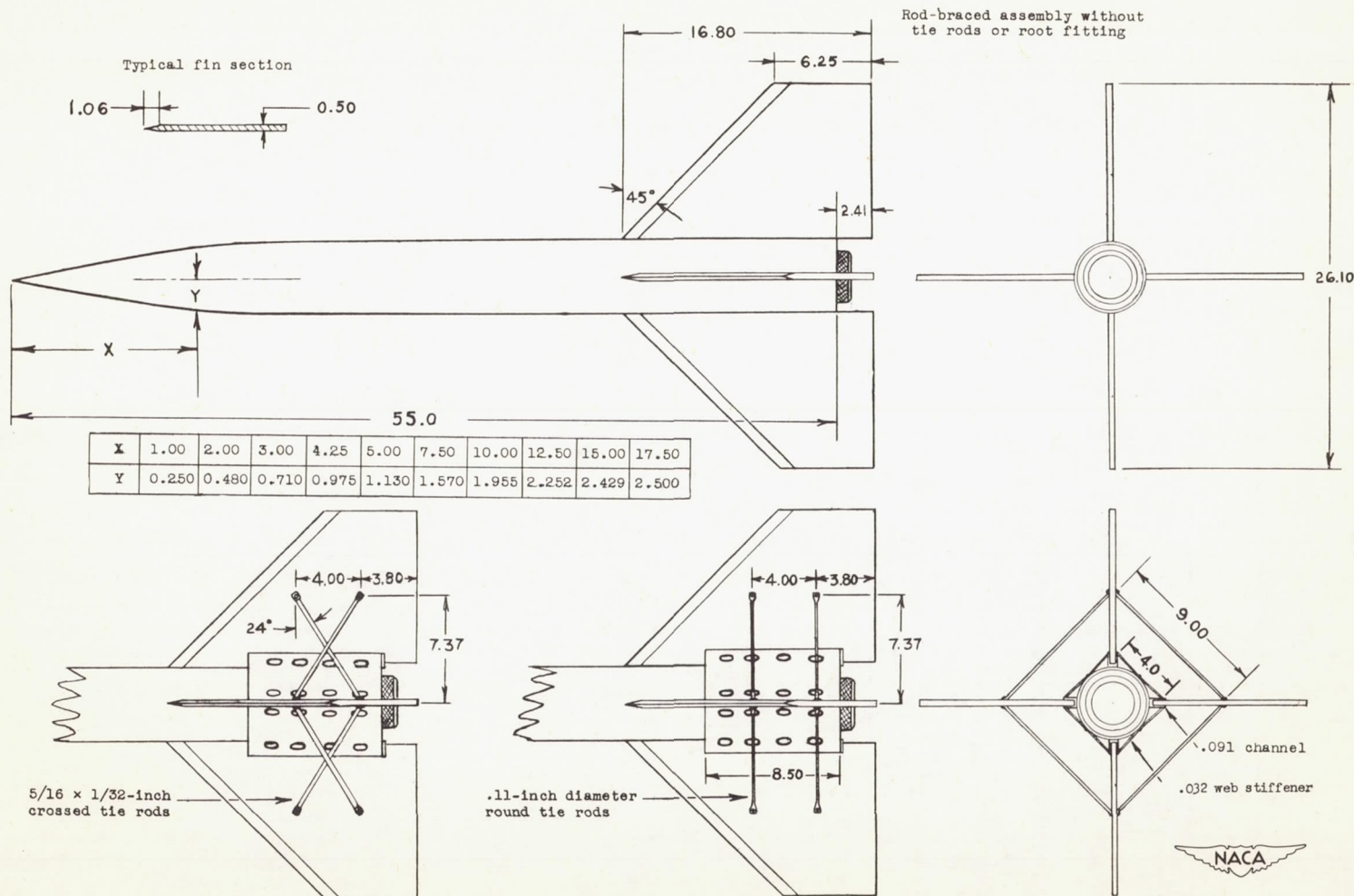
1. Morrow, John D., and Katz, Ellis: Flight Investigation at Mach Numbers from 0.6 to 1.7 to Determine Drag and Base Pressures on a Blunt-Trailing-Edge Airfoil and Drag of Diamond and Circular-Arc Airfoils at Zero Lift. NACA RM L50E19a, 1950.
2. Lindsey, W. F.: Drag of Cylinders of Simple Shapes. NACA Rep. 619, 1938.

TABLE I
FIN CONFIGURATIONS

	Rod braced	Cantilever
¹ Aspect ratio	2.04	3.20
Exposed area (4 fins), square feet	3.37	7.52
Root thickness, percent chord	2.94	5.00
Tip thickness, percent chord	7.90	5.00
Taper ratio $\left(\frac{\text{Tip chord}}{\text{Root chord}}\right)$	0.37	0.32

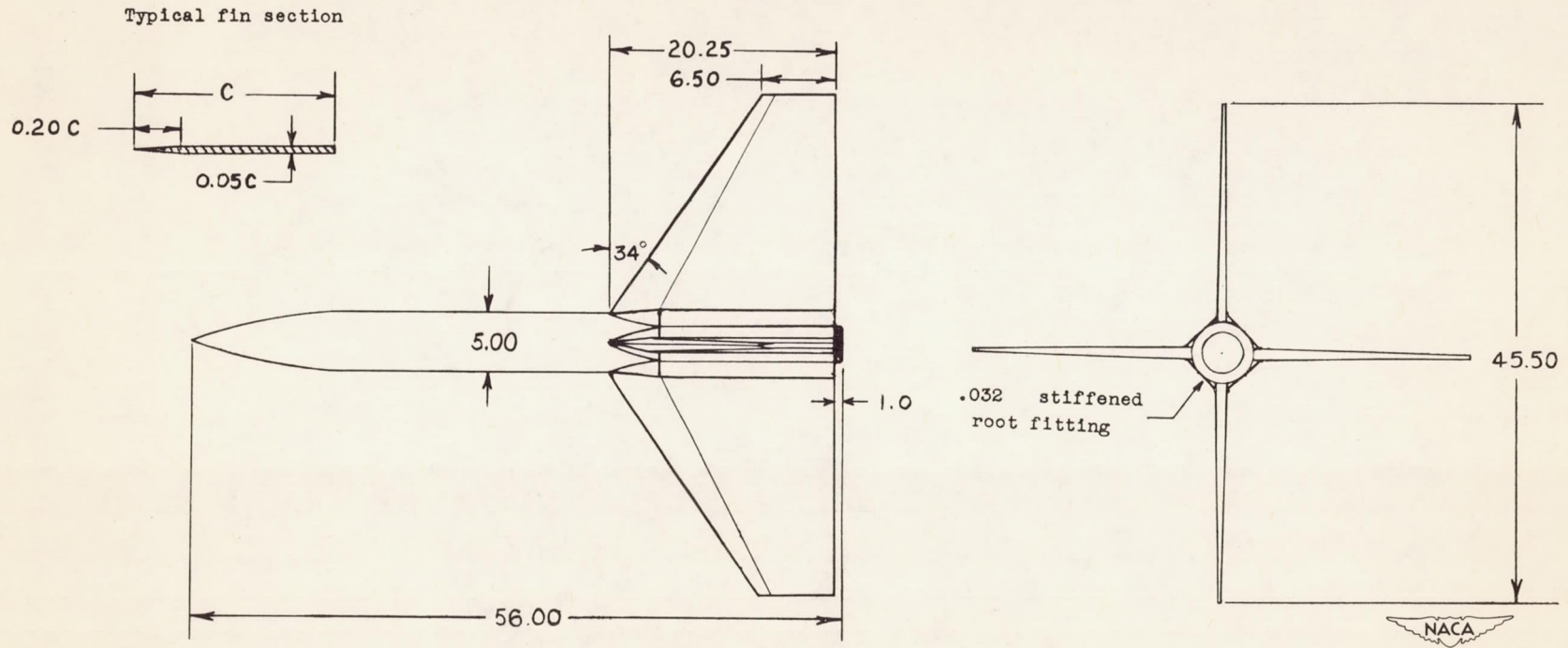
¹Based on total span and total area in one plane.





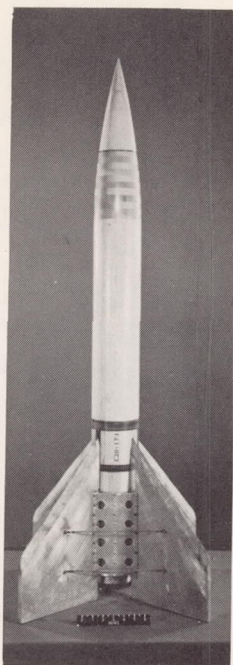
(a) Rod-braced configurations; not shown are the single round rod in the forward position and the crossed-round-rod configurations.

Figure 1.- Drawings of configurations tested. All dimensions in inches.

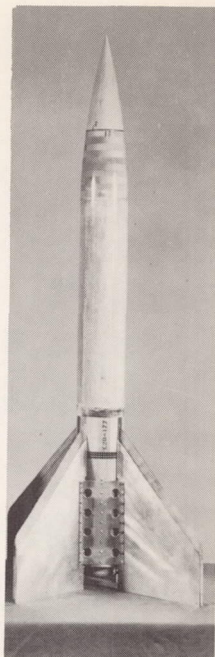


(b) Cantilever configuration.

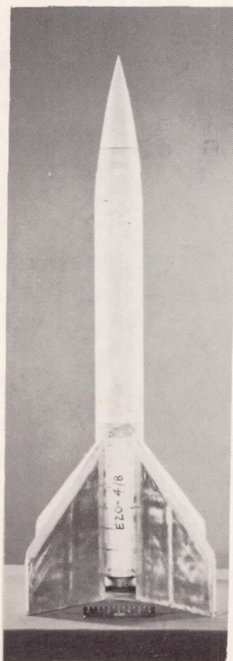
Figure 1.- Concluded.



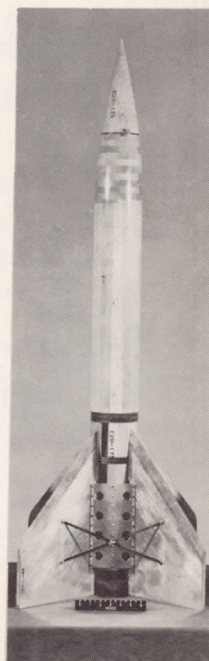
Two parallel round rods



Without tie rods



Without tie rods or root fitting

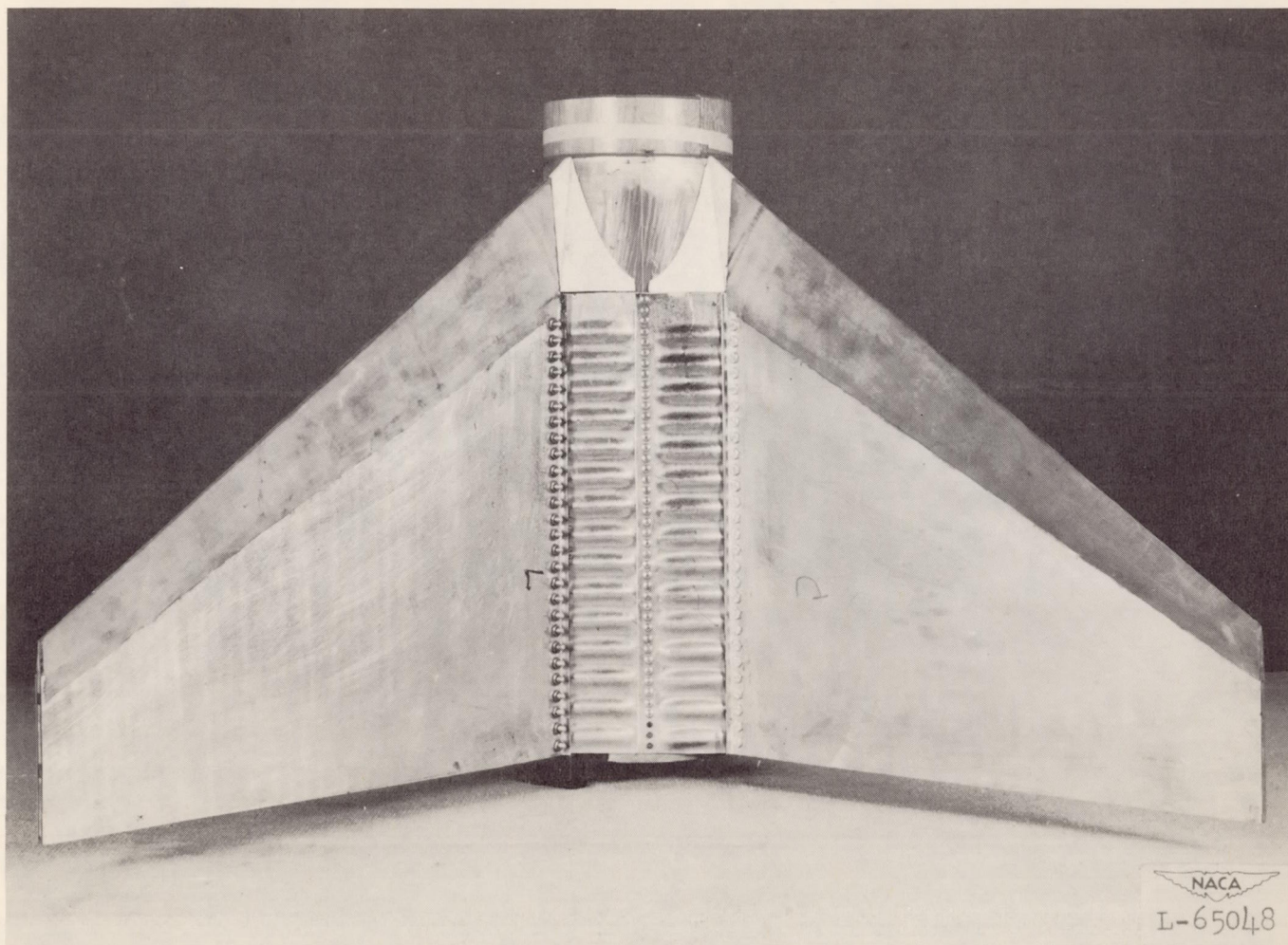


Crossed flat rods

(a) Rod-braced configurations.

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Figure 2.- Photographs of fin assemblies tested. Not included are the crossed round rod and the single round rod in the forward position fin assemblies.



(b) Cantilever fin assembly.

Figure 2.- Concluded.

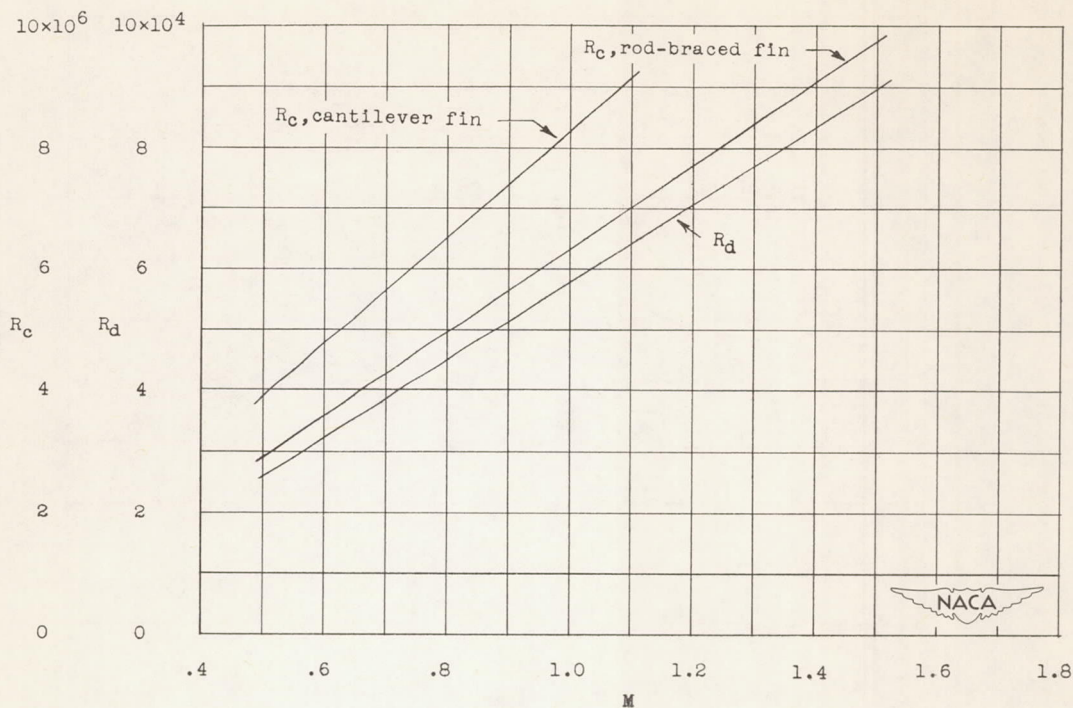


Figure 3.- Reynolds numbers for models tested, based on mean aerodynamic chord (R_c) and based on round-rod diameter (R_d).

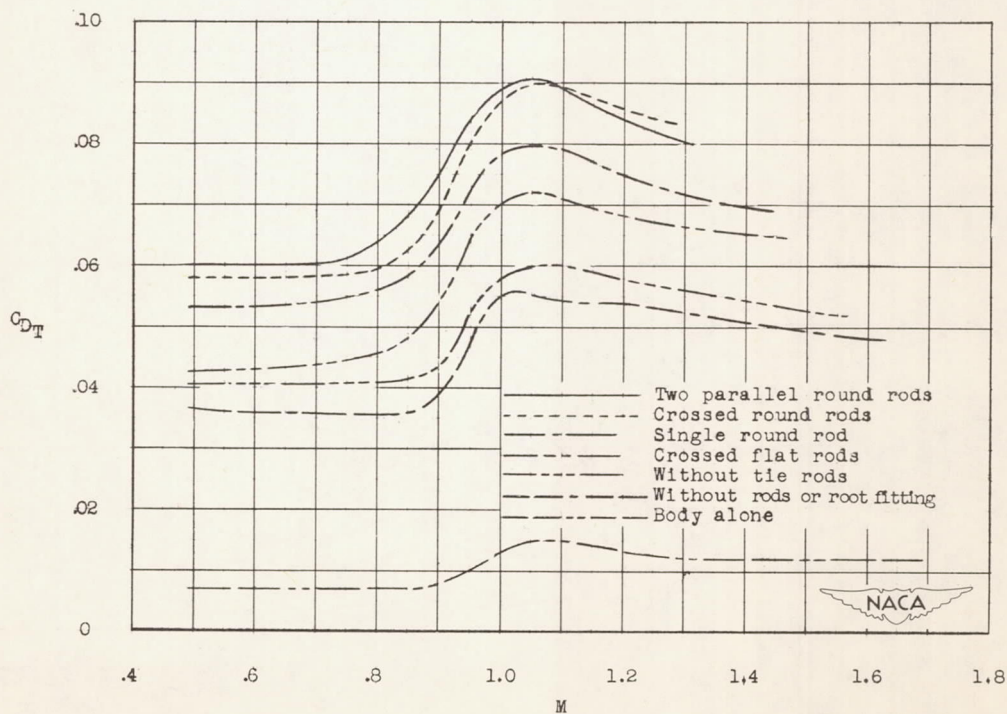


Figure 4.- Drag coefficients of complete rod-braced models and body alone.

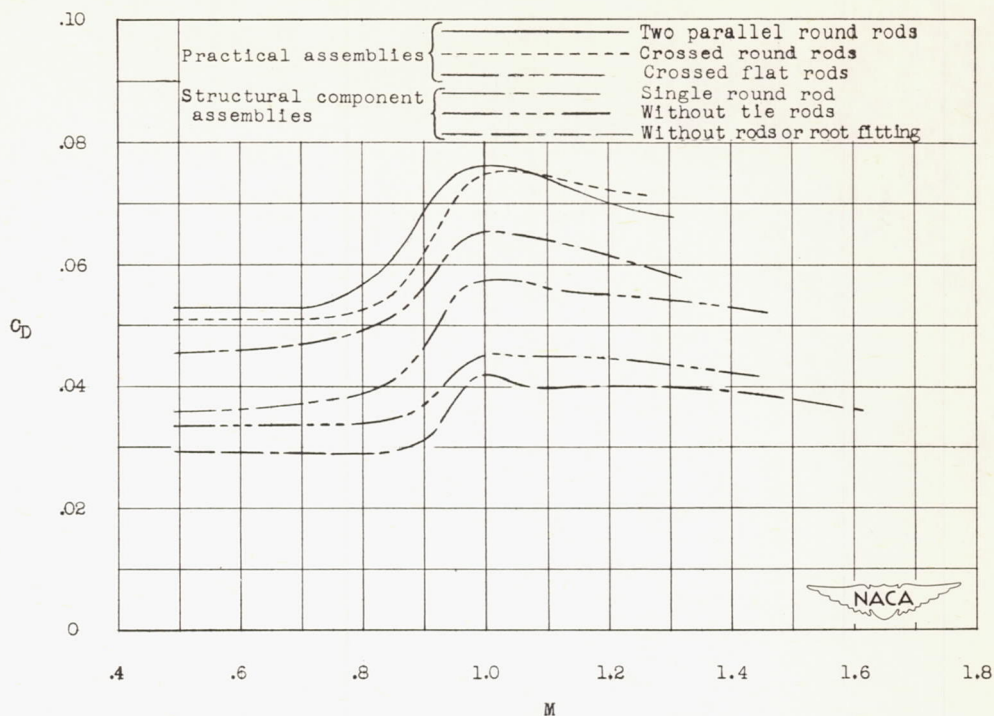


Figure 5.- Drag of practical rod-braced fin assemblies and assemblies tested to determine drag of structural components.

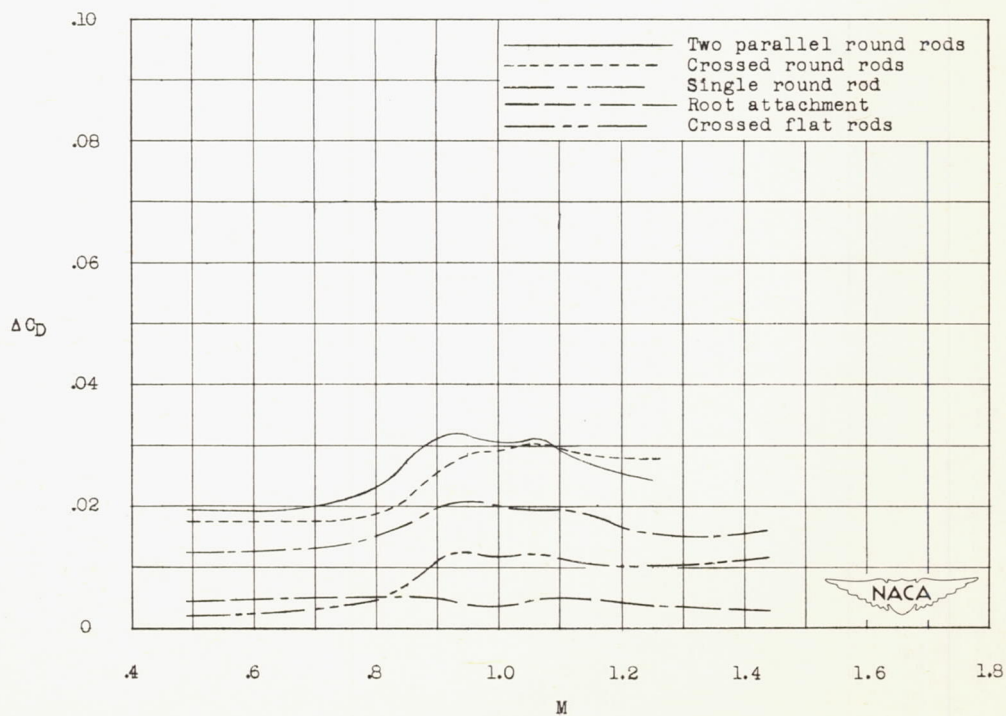


Figure 6.- Incremental drag coefficients of various fin components.

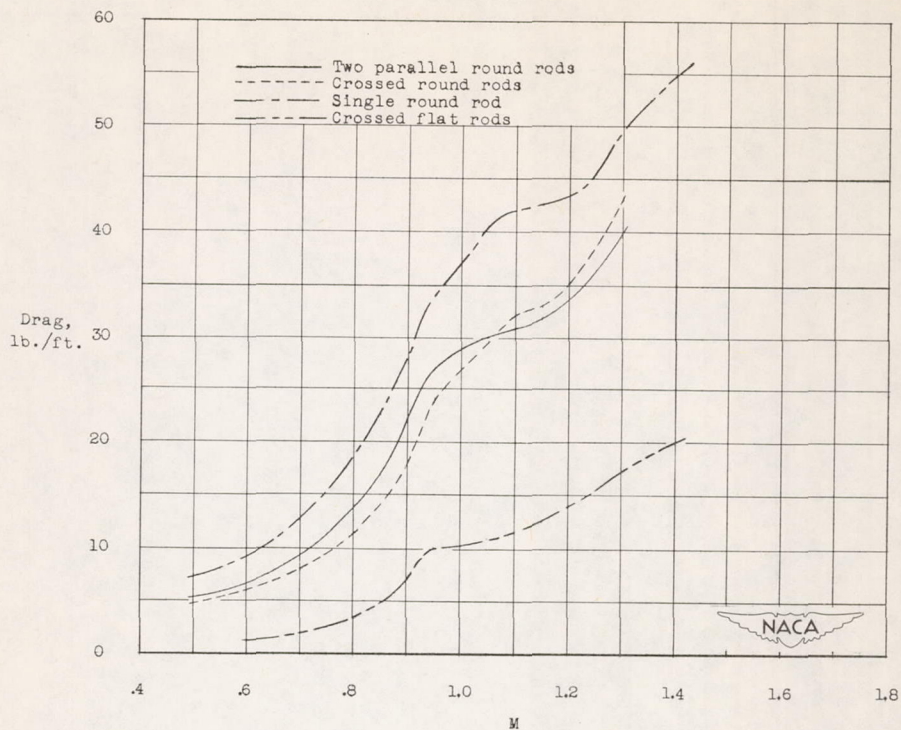


Figure 7.- Drag of tie rods in pounds per foot of projected rod length normal to the center line of the body for standard sea-level conditions. Dimensions of the tie rods are: 0.11-inch-diameter round rods and $\frac{1}{32}$ - by $\frac{5}{16}$ -inch flat rods.

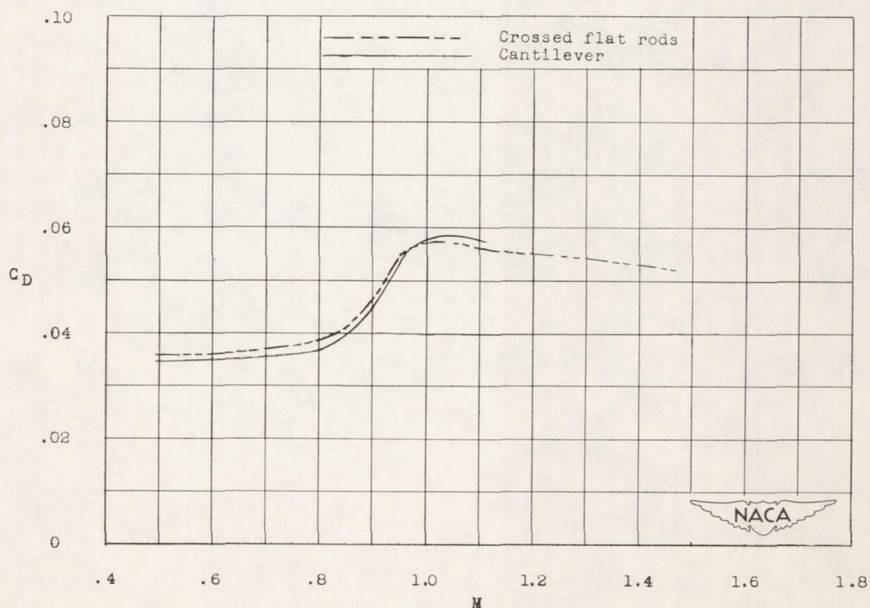


Figure 8.- Comparison of drag coefficients of cantilever fin assembly with the most efficient rod-braced fin assembly.